

# Close-up of primary and secondary asteroseismic CoRoT targets and the ground-based follow-up observations

K Uytterhoeven<sup>1</sup>, E Poretti<sup>1</sup>, M Rainer<sup>1</sup>, L Mantegazza<sup>1</sup>, W Zima<sup>2</sup>,  
C Aerts<sup>2,3</sup>, T Morel<sup>2</sup>, A Miglio<sup>4</sup>, K Lefever<sup>2</sup>, P J Amado<sup>5</sup>,  
S Martín-Ruiz<sup>5</sup>, P Mathias<sup>6</sup>, J C Valtier<sup>6</sup>, M Paparó<sup>7</sup>, J M Benkő<sup>7</sup>  
and the CoRoT/SWG Ground-based Observations Working Group

<sup>1</sup> INAF-Brera Astronomical Observatory, Via E. Bianchi 46, 23807 Merate, Italy

<sup>2</sup> Institute of Astronomy, KULeuven, Celestijnenlaan 200D, 3001 Leuven, Belgium

<sup>3</sup> Department of Astrophysics, University of Nijmegen, IMAPP, PO Box 9010, 6500 GL Nijmegen, the Netherlands

<sup>4</sup> Institut d'Astrophysique et de Géophysique de l'Université de Liège, Allée du 6 Août 17, 4000 Liège, Belgium

<sup>5</sup> Instituto de Astrofísica de Andalucía (CSIC), Apartado 3004, 18080 Granada, Spain

<sup>6</sup> Observatoire de la Côte d'Azur, GEMINI, CNRS, Université Nice Sophia-Antipolis, BP 4229, 06304 Nice Cedex 4, France

<sup>7</sup> Konkoly Observatory, P.O. Box 67, 1525 Budapest, Hungary

E-mail: [katrien.uytterhoeven@brera.inaf.it](mailto:katrien.uytterhoeven@brera.inaf.it)

**Abstract.** To optimise the science results of the asteroseismic part of the CoRoT satellite mission a complementary simultaneous ground-based observational campaign is organised for selected CoRoT targets. The observations include both high-resolution spectroscopic and multi-colour photometric data. We present the preliminary results of the analysis of the ground-based observations of three targets. A line-profile analysis of 216 high-resolution FEROS spectra of the  $\delta$  Sct star HD 50844 reveals more than ten pulsation frequencies in the frequency range 5–18 d<sup>−1</sup>, including possibly one radial fundamental mode (6.92 d<sup>−1</sup>). Based on more than 600 multi-colour photometric datapoints of the  $\beta$  Cep star HD 180642, spanning about three years and obtained with different telescopes and different instruments, we confirm the presence of a dominant radial mode  $\nu_1 = 5.48695$  d<sup>−1</sup>, and detect also its first two harmonics. We find evidence for a second mode  $\nu_2 = 0.3017$  d<sup>−1</sup>, possibly a g-mode, and indications for two more frequencies in the 7–8 d<sup>−1</sup> domain. From Strömgren photometry we find evidence for the hybrid  $\delta$  Sct/ $\gamma$  Dor character of the F0 star HD 44195, as frequencies near 3 d<sup>−1</sup> and 21 d<sup>−1</sup> are detected simultaneously in the different filters.

## 1. The simultaneous ground-based follow-up observations of CoRoT targets

The asteroseismic window of the CoRoT satellite mission aims at the monitoring of several types of pulsators along the Main Sequence. To optimise the science results, its targets are carefully chosen and selected. Preparatory observations from the ground have been a key stone in the selection process [1]. With the CoRoT satellite successfully launched (December 2006), simultaneous ground-based observations are very important and are complementary to the space

data. Multi-colour photometry provides colour information, which allows identification of the degree  $\ell$  by means of amplitude ratios and phase shifts, while high-resolution spectroscopy allows the detection of high-degree modes and the identification of both the degree  $\ell$  and the azimuthal order  $m$ .

In this framework a simultaneous ground-based observing campaign was organised by the CoRoT/SWG Ground-based Observations Working Group. Large Programme proposals (i.e. guaranteed observing time during four observing seasons) were submitted and accepted at ESO La Silla (FEROS/2.2m; 10+5 nights per semester), Observatoire de Haute Provence (SOPHIE/1.92m; 10+5 nights per semester) and Calar Alto Astronomical Observatory (FOCES/2.2m; 10+10 nights per semester), with the aim to obtain multi-site time-series of high-resolution spectra of a selection of  $\delta$  Sct,  $\gamma$  Dor,  $\beta$  Cep and Be CoRoT primary and secondary targets.

The first two observing seasons (winter 2006-2007 and summer 2007), (nearly) coinciding with CoRoT's IR01 (first Initial Run) and LRc1 (first Long Run in the center direction), have been successfully completed. Table 1 gives an overview of the targets and the amount of spectra obtained.

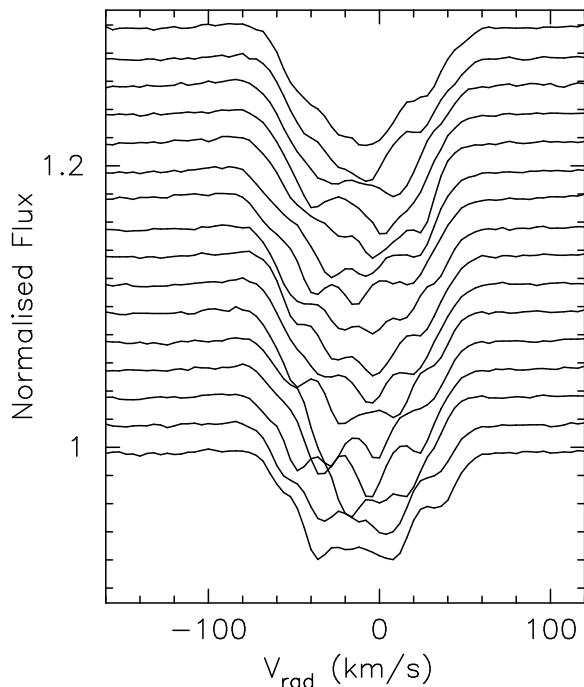
In addition to the Large Programmes, and in continuation of a project started three years ago, observing time has been awarded at smaller telescopes with multi-colour photometric instruments (Strömgren photometry: 90cm@Sierra Nevada Observatory (SNO), 1.5m@San Pedro Mártir Observatory (SPMO); Geneva photometry: 1.2m Mercator@Observatorio Roque de los Muchachos (ORM); Johnson photometry: Konkoly Observatory (KO)). In particular, 18 and 14 consecutive nights have been awarded with the  $uvby\beta$  photometers at SPMO and SNO, respectively, in Nov-Dec 2006 and 2007.

**Table 1.** Logbook of the spectroscopic observations, obtained in Jan-Feb 2007 and May-Jul 2007 with the FEROS, SOPHIE and FOCES instruments, dedicated to a selection of targets of the CoRoT IR01 (Feb-Apr 2007), LRc1 (summer 2007) and LRa1 (winter 2007-2008) runs. The different columns give the target name, its V magnitude, spectral type, variable type, name of the CoRoT run, amount of spectra obtained with FEROS, SOPHIE and FOCES, respectively. The targets indicated in boldface are discussed in this paper.

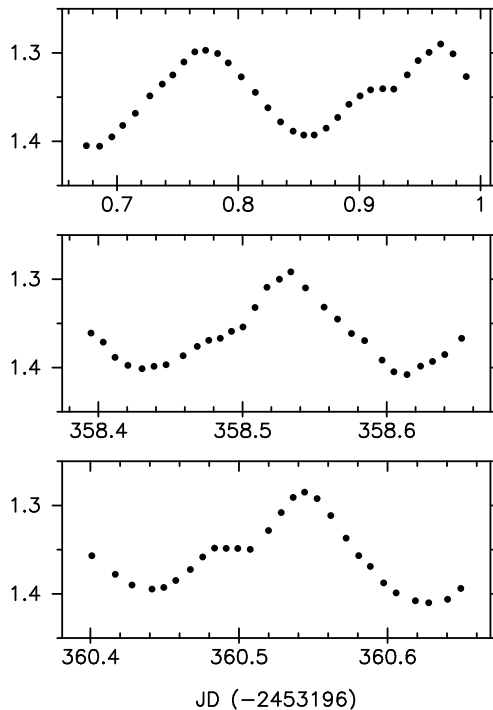
target	V	Sp.T.	type	CoRoT run	FEROS	SOPHIE	FOCES
<b>HD 50844</b>	9.09	A2	$\delta$ Sct	IR01	216		
HD 50747	5.45	A4	SB2	IR01	17	14	6
HD 51106	7.35	A3m	SB2	IR01	15	14	4
HD 50846	8.43	B5	EB	IR01	16	12	4
HD 49434	5.74	F1V	$\gamma$ Dor	LRa1	71	444	75
HD 50209	8.36	B9Ve	Be star	LRa1	68		
HD 181555	7.52	A5	$\delta$ Sct	LRc1	343	66	285
HD 174966	7.72	A3	$\delta$ Sct	LRc1			119
<b>HD 180642</b>	8.27	B1.5III	$\beta$ Cep	LRc1	213	35	
HD 181231	9.69	B9.0V	Be star	LRc1	72		

SB2=double-lined spectroscopic binary; EB=eclipsing binary

In the next sections we report on the preliminary results of the analysis of the ground-based datasets of the  $\delta$  Sct star HD 50844 and the  $\beta$  Cep star HD 180642, and give an outlook towards an interesting candidate CoRoT target, the hybrid  $\delta$  Sct/ $\gamma$  Dor star HD 44195.



**Figure 1.** A set of combined profiles of HD 50844, constructed using the LSD method. The individual profiles are slightly shifted in flux level for visibility reasons.



**Figure 2.** Some lightcurves (Strömgren  $v$ ) of HD 180642 obtained at SPMO (top) and SNO (middle and bottom). A non-sinusoidal behaviour, and a 'stillstand', is clearly present. The Julian date is given with respect to JD 2453196.

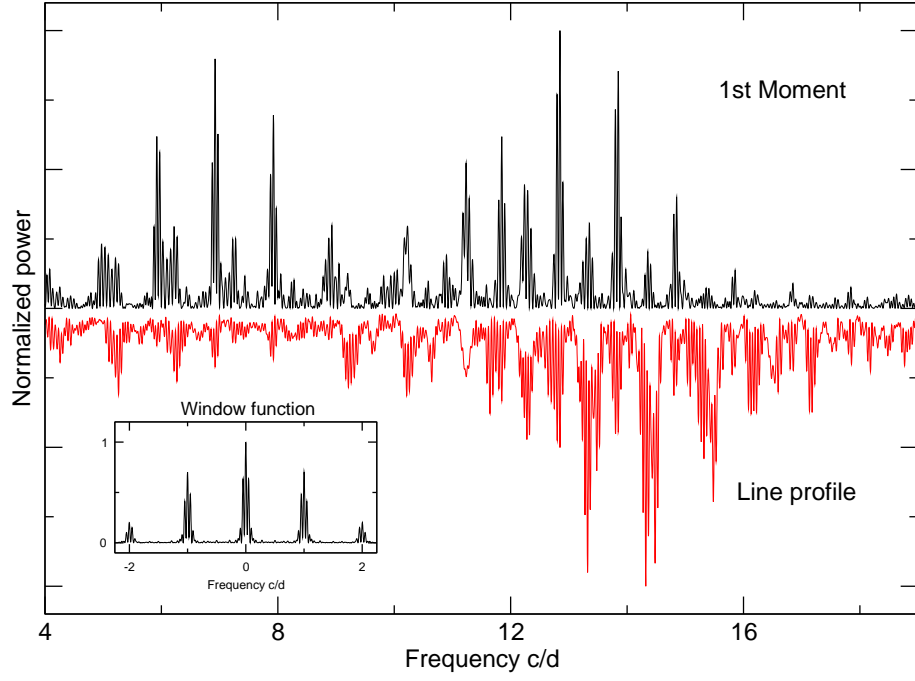
## 2. The $\delta$ Sct star HD 50844

The  $\delta$  Sct star HD 50844 was observed as secondary target around the solar-like oscillator HD 49933 during CoRoT's IR01 (Feb-Apr 2007). Being a faint target ( $V = 9.09$ ), obtaining ground-based high-resolution spectra with sufficiently high signal-to-noise ratio ( $S/N > 100$ ) proved to be a challenging task. In total 216 échelle spectra were obtained with FEROS/2.2m at ESO, La Silla, during the nights of 1–10 and 24–28 January 2007 (see Table 1).

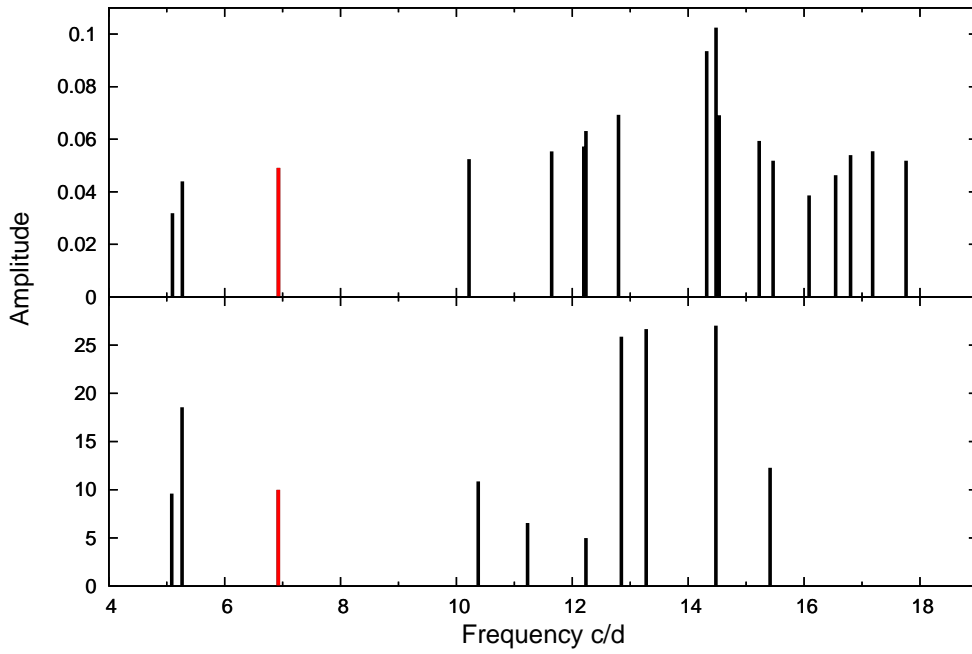
Two different teams (INAF-Brera and KULeuven), analysed the spectra independently, using different cross-correlation methods to increase the  $S/N$ . One team used the LSD deconvolution method [2], whereby taking into account more than 1000 lines (Figure 1), while the other constructed combined profiles from 9 carefully selected lines.

Frequencies were sought for in the line-profile moments [3] and in the pixel-to-pixel intensity variations [4] of the combined profiles using Fourier analysis and least-squares fitting methods. The frequency spectrum (Figure 3) shows strong aliasing and looks particularly difficult to unravel due to closely spaced modes. In the variations of the first moment, more sensitive to the detection of low-degree modes ( $\ell < 4$ ), at least nine modes in the range  $6\text{--}15\text{ d}^{-1}$  are found, with dominating frequencies near  $6.9$  and  $12.8\text{ d}^{-1}$ . The pixel-to-pixel variations, which allow also the detection of high-degree modes, show the presence of at least thirteen frequencies in the range  $5\text{--}18\text{ d}^{-1}$ , with dominating frequency peaks between  $14$  and  $15\text{ d}^{-1}$ . Only one mode detected in the moment variations was not detected in the pixel-to-pixel variations and therefore can be considered as a 'bona fide' low-degree mode. The detected modes are represented in Figure 4.

Preliminary identification of the associated modes, using the phase and amplitude variations



**Figure 3.** Power spectra of the first moment (top) and pixel-to-pixel intensity variations (bottom) of the combined profiles of HD 50844. The inset shows the associated window function.



**Figure 4.** Frequencies detected in the line-profile variations of HD 50844. The upper and lower panel show the results obtained from the pixel-to-pixel analysis and the moment method (third moment), respectively. The frequency possibly identified as a radial fundamental mode is indicated in red. The amplitudes are given on a relative scale.

across the line-profiles [4], results in prograde modes for the frequencies greater than  $13 \text{ d}^{-1}$ , and retrograde modes for the frequencies smaller than  $6 \text{ d}^{-1}$ . The frequency  $6.92 \text{ d}^{-1}$  has the largest amplitude in *uvby* photometry; this fact combined with the preliminary spectroscopic analysis suggests a radial fundamental mode. A more indepth study of the variability of HD 50844 is currently ongoing.

We expect that the CoRoT time-series of HD 50844, which will be released at the end of 2007, shall overcome the strong aliasing and will unravel the complex oscillation pattern with closely spaced frequencies that we see from the ground. Accurately defined frequencies and a clear mode-identification are needed for future asteroseismic modelling of this  $\delta$  Sct star.

### 3. The $\beta$ Cep star HD 180642

HD 180642 is to date the only  $\beta$  Cep pulsator selected as primary or secondary target for the CoRoT mission. Consequently, expectations are high for this sole representative of the  $\beta$  Cep class of pulsators in CoRoT's core programme. In the framework of the ground-based preparatory programme HD 180642 was monitored in 2004 and 2005 with several photometers (at SPMO, SNO and KO), while it was already the target of a long-term programme at the Mercator telescope since 2001. Simultaneously with the CoRoT observations (LRc1, summer 2007), about 240 high-resolution spectra (see Table 1) were obtained with the FEROS and SOPHIE instruments. We report here only on the analysis of the photometric data and a few exploratory FEROS spectra that were taken in 2005, for which a logbook is given in Table 2. The analysis was carried out by teams at KULeuven, INAF-Brera and Liège.

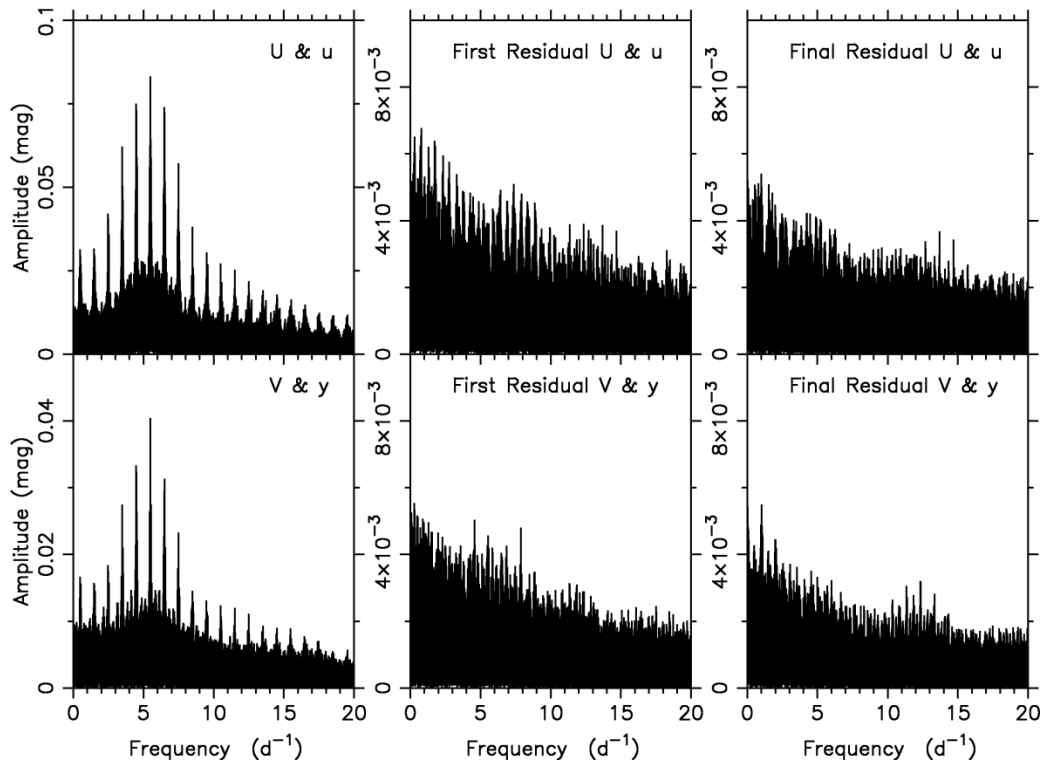
**Table 2.** Logbook of the photometric observations of HD 180642 obtained with P7/Mercator (7 Geneva filters), the Danish photometers at SPMO and SNO (Strömgren *uvby*) and the 50cm at KO (Johnson V), the available HIPPARCOS (HIP) data, and the spectra obtained with FEROS in 2005. The different columns give an identifier of the telescope or the observatory, the total timespan of the data ( $\Delta T$ , expressed in days) and the number N of datapoints.

	$\Delta T$	N		$\Delta T$	N
Mercator	1184	171	KO	319	69
SNO	359	235	HIP	1091	88
SPMO	5.3	113	FEROS	2	11

In the lightcurves of HD 180642 (Figure 2) the remarkable feature of a 'stillstand' is noticed (cfr. BW Vul [5]), which is possibly caused by a shockwave.

To improve the frequency resolution, we combined all the UV ( $\sim \lambda 3600 \text{ \AA}$ ), blue ( $\sim \lambda 4500 \text{ \AA}$ ) and violet ( $\sim \lambda 5500 \text{ \AA}$ ) data and searched for frequencies using standard Fourier analysis methods. We confirm [6] the presence of a dominant frequency  $\nu_1 = 5.48695 \text{ d}^{-1}$ , together with its harmonics  $2\nu_1$  and  $3\nu_1$  (Figure 5), which can unambiguously be identified as a radial mode  $\ell = 0$ , based on the amplitude ratios. By multiplying the normalised periodograms of the V, *y* and HIPPARCOS data [7], evidence was found for  $\nu_2 = 0.3017 \text{ d}^{-1}$  or one of its aliases, which is likely a g-mode, and possibly two other frequencies between 7 and  $8 \text{ d}^{-1}$ .

From the FEROS spectra listed in Table 2 we derived abundances consistent with those of B stars in the solar neighbourhood, but with a mild nitrogen excess. We obtained  $Z = 0.0106 \pm 0.0016$ . Modelling of the radial mode  $\nu_1$ , using the new solar mixture [8] (which is consistent with the derived abundances), gives, contrary to the old solar mixture [9], satisfying results when using OP opacities, while OPAL opacities do not predict an unstable mode for a  $\sim 10 M_{\odot}$  star, such as HD 180642.



**Figure 5.** The periodograms for the combined UV (top left) and violet (bottom left) datasets of HD 180642. The middle panels show the periodograms after prewhitening with  $\nu_1$ ,  $2\nu_1$  and  $3\nu_1$ , while the right panels show the periodograms after subsequent prewhitening with  $\nu_2$ ,  $\nu_3$  and  $\nu_4$ .

The next steps in understanding the variable behaviour of HD 180642 will be the analysis of the recently obtained spectroscopic time-series (Table 1), of new photometric CCD observations from KO, and of the CoRoT timeseries. From the complementary spectroscopic and space data we expect to study the shock wave, to unravel the frequencies at low amplitude and to identify the g-mode(s), which will allow to probe the deep interior of HD 180642.

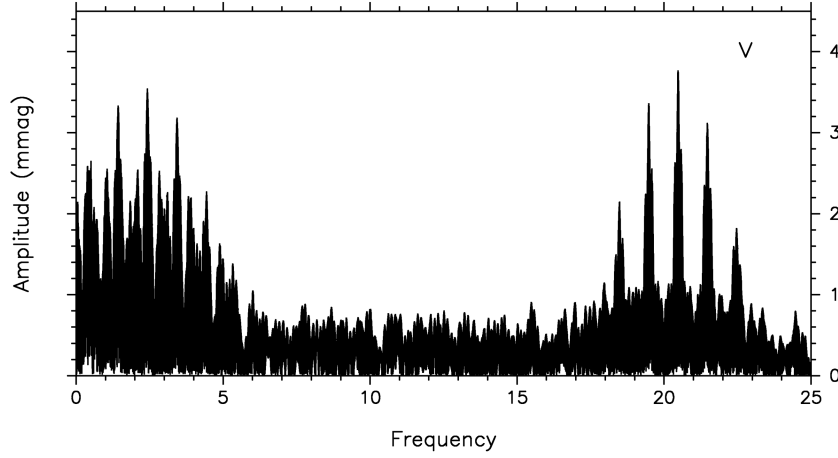
#### 4. The hybrid $\delta$ Sct/ $\gamma$ Dor star HD 44195

The F0 star HD 44195 ( $V = 7.56$ ) is visible in the eyes of CoRoT (LRa not earlier than winter 2009) and is visible in the MOST viewing zone. For both missions the star still has to be selected.

From line-profile variations HD 44195 is classified as a  $\gamma$  Dor suspect [10], while  $\delta$  Sct type variations are detected in multicolour photometry [1]. This makes HD 44195 an interesting hybrid variable, showing both p- and g-mode oscillations. As observational evidence for self-excited hybrid stars is scarce, a profound study of this star is particularly very interesting.

We observed HD 44195 in Nov-Dec 2006 with the *uvby* photometers at SPMO (18 nights) and SNO (14 nights). Similar observations are scheduled for Nov-Dec 2007. The frequency spectrum associated to the  $v$  magnitude variations shows clearly frequencies in both the  $\gamma$  Dor and  $\delta$  Sct region (Figure 6).

Besides an indepth study of the photometric dataset, we hope to obtain a spectroscopic timeseries to investigate the genuinity of the hybrid variability, and to perform a mode-identification with the aim to constrain the position of HD 44195 in the HR-diagram. Given the opportunity to probe both the deep layers and the surface of the star, and to investigate the link



**Figure 6.** Frequency spectrum of HD 44195 associated to the  $v$  data obtained at SPMO in 2006. The hybrid character becomes clear as frequency peaks near  $3 \text{ d}^{-1}$  and  $21 \text{ d}^{-1}$  occur simultaneously, which are typical for  $\gamma$  Dor and  $\delta$  Sct pulsators, respectively.

between  $\gamma$  Dor and  $\delta$  Sct pulsators, we propose the hybrid variable HD 44195 as an excellent target for both MOST and CoRoT.

## 5. Concluding remarks

We obviously are in a challenging era of asteroseismology. The preparatory work and the simultaneous ground-based observations of the CoRoT mission require a huge effort of the asteroseismic community. Challenging objects are chosen (e.g. faint targets, fast rotating stars) and in more than one way are we pushing the limits. The ambitious choice of targets asks for new methodologies and analysis techniques, and requires a close collaboration between theoreticians and observers. With joined forces, with shared expertise and with complementary data from space and from the ground we have excellent prospects to probe the interiors of stars.

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